

## SECTION 24

### STRUCTURAL STEEL

#### 1.24.1 DESIGN

The AASHTO Standard Specifications for Highway Bridges (with current interims), with modifications specified under Section 3 of this Manual, shall govern the design.

#### 1.24.2 TYPE OF STEEL

- (a) Structural steel shall conform to the AASHTO M 270M/M 270 (ASTM A 709M/A 709), grades designated in Table 10.2A of the AASHTO Standard Specifications for Highway Bridges. Metric designations shall be used.
- (b) The use of Grades 250, 345 and 345W is permitted. The use of a higher strength steel or hybrid girders shall be subject to the approval of the Manager, Bureau of Structural Engineering. When a higher strength steel is considered, the welding procedure that is required to fabricate members shall also be submitted for approval.
- (c) The use of AASHTO M 270M/M 270 (ASTM A709), GRADE 345 W, “weathering steel”, is subject to the cleaning and painting requirements that are specified in Subsection 503.15 of the NJDOT Standard Specifications.
- (d) All structural steel plans shall have the following note shown thereon:  
  
STRUCTURAL STEEL: AASHTO M 270M/M 270, GRADE \_\_\_\_ (ASTM A709 M/A 709, GRADE\_\_\_\_) with Supplementary Requirements for Notch Toughness for all member components marked (T).
- (e) It shall be the responsibility of the Structural Design Engineer to designate the main load carrying member components that are subject to tensile stress. For this purpose, the designation (T) shall be noted on the contract plans.

The components to be designated (T) shall include flanges, webs, and splice plates of the welded stringers, girders, or rolled beams (also see Guide Sheet Plate 3.9-22.) The above note and designations shall be verified on the shop plans.

#### 1.24.3 SPAN TYPE SELECTION

- (a) Simple and continuous stringers are within the range of span types that can be considered for the majority of structures. The choice should be made on the basis of judgment, economy, appearance and serviceability.
- (b) Redundant type (multiple load path) systems shall always be used. Should the need for non-redundant (single load path) systems be unavoidable, their use shall be subject to approval, in writing, by the Manager, Bureau of Structural Engineering.

The approval shall be obtained prior to the Preliminary Plan submission and before beginning final design development. Such approval will be subject to the special design, fabrication, and plant inspection provisions of the AASHTO "Fracture Control Plan" (see Subsection 1.24.5).

- (c) Continuous spans are only recommended for structures founded on rock, point bearing piles, or unyielding soils. The soil may be considered unyielding if the following conditions are met:
  - The bearing capacity is at least 200 kPa.
  - The available soil data permits the settlement to be reliably computed.
  - The effects of the differential settlement are accounted for in the design of the superstructure.

Design differential settlement shall be considered at 25 millimeters maximum.

- (d) Structures containing pin and hanger connections for suspended/cantilever spans should be avoided wherever possible. If warranted, suspended/cantilever span design shall be subject to approval, in writing, by the Manager, Bureau of Structural Engineering prior to the Preliminary plan submission.

Pin and hanger connections may only be utilized on redundant (multiple load path) systems. Members shall be restrained against lateral movement on the pins and against lateral distortion due to bridge skew or curvature. Pin and hanger connections shall be designed in accordance with the AASHTO Standard Specifications of Highway Bridges.

#### **1.24.4 ECONOMICS OF STRINGER DESIGN**

- (a) In the design of welded plate girders, consideration should be given to minimizing the number of transverse intermediate stiffeners.

The use of transverse intermediate stiffeners is discouraged to the extent practical in exercising good judgment in design engineering practice for the following reasons:

- (1) Welding to the parent metal in itself introduces a discontinuity and should be avoided as much as possible, according to one concept of thought in the science of Fracture Control Mechanics.

- (2) Elimination of projections and obstructions and the resulting flat surfaces optimize the chances of improved quality of workmanship in the cleaning and painting of the structural steel both in the fabricating shop, initial field coating and future maintenance painting.
  - (3) Fabricating cost differentials between welding stiffeners versus use of additional material in the main components of girders are not overwhelmingly significant and should be considered during design.
- (b) Consideration shall also be given to minimizing the number of butt welded flange plate transitions. Plate size transitions may be located at the field splice so that butt welding requirements are either reduced or eliminated. It is the Designer's responsibility to check the availability of plate sizes in order to determine the location of shop splices for flange plates.
  - (c) Reduction of material mass is not necessarily the ultimate factor in determining span type selection. Material mass of the stringers may represent about 25% of the completed, in-place cost. The bulk of the cost is in fabrication, delivery and erection.

According to some concepts of thought in the steel fabricating industry, any initial construction cost savings in reduction of material mass may not be overwhelmingly significant when fabricating, shop fit-up, and erection cost differentials are considered. Simplification and repetition of details, reduction of fabricating operations, and ease of erection are often better means of achieving minimum cost.

#### **1.24.5 FRACTURE CONTROL PLAN**

- (a) The construction specifications provide that "... steel bridge members or member components designated as Fracture Critical Members (FCM's) shall be subject to the provisions of the AASHTO Guide Specifications For Fracture Critical Non-Redundant Steel Bridge Members..."
- (b) Fracture critical members or member components (FCM's) are tension members or tension components of members whose failure would be expected to result in collapse of the bridge.
- (c) The responsibility for determining which, if any, bridge member or member component is in the FCM category shall rest with the Structural Design Engineer.
- (d) If it is determined that any member or member component is in the FCM category, the following note shall be shown on the structural steel plans:

**Fracture Critical Members: Members or member components designated as FCM shall be subject to the provisions of the 1978 AASHTO Guide Specifications for Fracture Critical Non-Redundant**

**Steel Bridge Members (with current interims) and NJDOT  
Amendments.**

Shop drawings shall be reviewed by the Structural Design Engineer accordingly.

**1.24.6 COMPOSITE DESIGN**

- (a) Steel stringers with a concrete deck slab shall normally be designed as composite structures, assuming no temporary supports will be provided for the beams or girders during placement of the permanent dead load.
- (b) Shear connectors shall be M 22 end welded studs. Height of studs depends on concrete haunch dimensions. Shear connectors shall penetrate at least 50 millimeters into the bottom mat of the deck slab, but the top of the stud head shall be 75 millimeters minimum below the top of the deck slab. Use of the same height stud on any one bridge is preferred.
- (c) See Page 1.3-13 for the negative moment area of continuous spans.

**1.24 7 CAMBER**

- (a) Simple Spans. The various conditions of dead load deflection and camber for each simple span stringer shall be tabulated on the structural steel plans as shown below:

DEAD LOAD DEFLECTIONS (MM)							CAMBER (MM)			
Stringer Number	Location	Structural Steel	Concrete Slab (Including Haunches)	Stay In Place Form And Added Concrete Thickness	Sidewalks Parapets Barriers	Future Paving Allowance	Total Dead Load Camber	Vertical Curve Ordinate	Architectural Camber	Total Camber Required
	Mid-Span									
	1/4 Point									

The column headed "Vertical Curve Ordinate" shall be used exclusively for simple span stringers located within the limits of a crest vertical curve. Where such stringers are located within the limits of a sag vertical curve, provision for its ordinates must be made within the concrete haunch. Consequently, the tabulation of its ordinates is unnecessary.

Total dead load camber is equal to the sum of the dead load deflections. An architectural camber of  $L/1.2$  millimeters, where  $L$  is the span length in meters, shall be provided for all simple span stringers unless the vertical curve ordinate meets this, in which case the architectural camber may be omitted. When establishing the depth of the concrete slab and haunch in composite design, the following items shall be considered:

1. Total camber required.
2. Girder dimensional tolerances per Section 3.5 of the ANSI/AASHTO/AWS Bridge Welding Code D1.5.
3. A minimum cover of 75 millimeters over the shear connectors.

When total camber is less than minimum that can be maintained in a beam (W Section) no camber is required but a note stating "Beams shall be placed with any mill camber up" shall be shown on the drawings.

- (b) Continuous and Cantilevered Spans. The various conditions of dead load deflections and cambers for each stringer shall be tabulated at the tenth point of spans and at the field splice points (at dead load points of contraflexure if field splices are not provided).

The illustrations on Page 1.24-6 to 8 show an example of a typical tabulation for a continuous span.

CAMBER TABLE																																						
			SPAN 1										SPAN 2										SPAN 3															
POINT NUMBER		Centerline	1	2	3	4	5	6	7	IP1	8	9	10	Centerline	11	12	IP2	13	14	15	16	17	IP3	18	19	20	Centerline	21	22	IP4	23	24	25	26	27	28	29	Ce
CAMBER	Steel	0											0													0												0
	Conc. Slab	0											0													0												0
	SIP Forms and Added Concrete Thickness	0											0													0												0
	S. D. L.	0											0													0												0
	V. C.	0																																				0
	Architec-tural	0												0													0											0
	TOTAL	0	C1=	C2=	C3=	C4=	C5=	C6=	C7=	C =	C8=	C9=	C10=	C11=	C12=	C =	C13=	C14=	C15=	C16=	C17=	C =	C18=	C19=	C20=	C21=	C22=	C =	C23=	C24=	C25=	C26=	C27=	C28=	C29=			

## CAMBER TABLE NOTES

1. The total camber as tabulated is assumed to be measured vertically to the top of the fully cambered web from a straight line drawn from the intersection of top of web and centerline of bearing at one end of the girder to the intersection of top of web and centerline of bearing at the other end of the girder.
2. The camber labeled "Steel" in the table is the camber required in the girder to offset the deflection due to the dead load of the steel in the girder.
3. The camber labeled "Conc. Slab" in the table is the camber required in the girder to offset the deflection due to the dead load of the concrete slab.
4. The camber labeled "SDL" in the table is the camber required in the girder to offset the deflection due to the superimposed dead load, that is, the curb, sidewalk, railing and future wearing surface.
5. The camber labeled "Stay-in-place forms and added concrete thickness" is the camber required in the girder to offset the deflection due to the weight of the stay in place forms and due to the weight of added concrete that is needed to meet the deck grades.
6. The camber labeled "VC" in the table is the camber required in the girder to follow the vertical curve. The Vertical Curve value shall be used exclusively for stringers located within the limits of a crest vertical curve. Where such stringers are located within the limits of a sag vertical curve, provision for its value must be made within the concrete haunch. Consequently, the tabulation of its values is unnecessary.
7. The camber labeled "Architectural Camber" shall be a value of  $L/1.2$  millimeters, where "L" is the span length in meters. If the vertical curve value provides this camber value, the architectural camber may be omitted.
8. Cambers listed in the table as positive are upward cambers.
9. Cambers listed in the tables as negative are downward cambers.
10. The cambers are tabulated in millimeters.

(c) Sag Cambers

Because of the objectionable appearance of a sag camber in a stringer, sag or negative cambers should be avoided. The following are a few guidelines on possible means of avoiding negative camber in a stringer:

- (1) Avoid sag vertical curves on bridges.
- (2) Never begin or end a superelevation transition or runoff in the middle of a span. Always begin or end transitions off the structure or, if this is impossible, begin or end the transition at a centerline of bearing or a centerline of pier.
- (3) Never place a sag camber in a straight stringer on a curved roadway in order to accommodate the variation in the theoretical bottom of slab elevation. The variation should be taken up in the haunch.
- (4) Upward dead load deflection may occur in some areas of continuous girders when the ratio of maximum to minimum span lengths becomes significant. There always is a possibility that computed camber built into the girder is not completely removed with the application of dead load. Camber due to a future wearing surface will remain when construction is completed. Additional camber may remain due to differences between design assumptions and actual girder performance.

#### **1.24.8 MULTIPLE SPAN STRUCTURES**

- (a) It is desirable, from an aesthetic viewpoint, that a uniform depth of concrete fascia be kept for the full length of the exposed fascia. All fascia beams shall be set so that the bottom of the top flanges will be aligned.
- (b) Stringers, beams, and girders shall generally be of uniform depth for the full length of the structure, except where changes in depth are absolutely necessary to meet underclearance requirements or where a change in depth is desirable to enhance the appearance of the structure. Changes in depth shall not normally be made in structures with varying spans. Interior stringers shall be made the same depth as the fascia stringer.

#### **1.24.9 DIAPHRAGMS AND X-FRAMES**

- (a) End diaphragms and their connections shall be designed for the effect of wheel loads which they may be required to support, for the effect of transverse movement of the bearing shoes due to temperature differences between the superstructure and substructure, and for the effect of all horizontal superstructure forces. The diaphragms and their connections shall be designed for the transverse force necessary to move the bearing shoes, in appropriate combinations with the other forces listed above.
- (b) For severely skewed ( $60 \text{ degrees} \pm$ ) structures, the structural steel layout should be examined to determine if the location of relatively stiff intermediate diaphragms placed normal to the stringers introduce detrimental stresses in diaphragms and stringers due to twisting. If the condition exists, consider staggering the spacing of the diaphragms or adding the following note:

**"Intermediate diaphragm connections to stringers shall be limited to finger-tight bolts in oversized holes until the dead loads are in place. The bolts shall be tightened after the deck is in place."**

- (c) See Guide Sheet Plates 3.9-1 to 3.9-6 for typical details of diaphragms and X-frames.

#### **1.24.10 TRANSVERSE INTERMEDIATE STIFFENERS**

- (a) See Subsection 1.24.5.
- (b) See Guide Plate 3.9-18.

#### **1.24.11 BEARING STIFFENERS**

See Guide Plate 3.9-20.

#### **1.24.12 CONNECTOR PLATES FOR INTERIOR DIAPHRAGM X-FRAMES**

See Guide Plate 3.9-19

#### **1.24.13 STABILITY DURING TRANSPORTATION AND ERECTION**

The stability of the stringers and girders during transport and erection is normally the responsibility of the Contractor, but, wherever possible, the design should be such that temporary bracing or diaphragms are not required. In reviewing shop drawings, Engineers shall satisfy themselves that the Contractor has properly met his contractual responsibilities in this respect.

#### **1.24.14 WELDED DETAILS**

- (a) Field Welding to stringers, plate girders or any major component of the structure shall not be permitted unless approved by the Manager, Structural Engineering, prior to the submission of working drawings.

Field welding in such cases shall conform to the following Sections of ANSI/AASHTO/AWS Bridge Welding Code D1.5. The following parameters shall be included in the Special Provisions:

- Pre-qualification of the proposed welding procedures shall be in accordance with Section 5, Part A.
- Qualifications of the welding operator shall be in accordance with Section 7, Part B.
- The Quality Control Inspector shall meet the qualifications specified in Section 6.1.3 and 12.16.

- All fillet welds shall be 100% Magnetic Particle (MT) tested in addition to Visual Inspection.
- (b) See Guide Sheet Plates 3.9-11 to 3.9-17 for symbols and notes to be included on contract plans for welded plate girders.
- (c) The ANSI/AASHTO/AWS Bridge Welding Code D1.5 promulgates the following concepts of inspection, which, in effect, are separate functions:
  - (1.) Fabrication/Erection Inspection and Testing (Quality Control) is to be performed by the Contractor or Fabricator as a mandatory requirement.
  - (2.) Verification Inspection and Testing (Quality Assurance) is the prerogative of the State.

Provisions in the ANSI/AASHTO/AWS Bridge Welding Code D1.5 requires that contract documents identify main members and also that contract documents identify groove welds in these members as to category of stress (tension, compression or reversals of stress). Both of these identifications are needed to define the extent of non-destructive testing required by the Contractor as a minimum level under QC inspection specifications.

Identification of the nondestructive inspection required for all welds included in Section 6.7, Parts B and C, of the ANSI/AASHTO/AWS Bridge Welding Code D1.5, shall be accomplished by providing symbols and notes as per paragraph (b) above. This essentially fulfills the requirement of the Bridge Welding Code.

For main member components in structure types such as trusses, bents, towers, box girders etc., it shall be the Structural Design Engineer's responsibility to identify such members and welds as part of the details on the contract drawings with the appropriate welding and NDT symbols.

- (d) Certain miscellaneous details (supports for screed rails, steel deck forms, miscellaneous connection plates, gussets, etc.) shall normally not be welded by the use of fillet welds (regardless of the direction of weld), plug welds, or tack welds to members or parts subject to tensile stress. At locations where welding cannot be avoided, the maximum stress at the point of attachment shall not exceed the allowable fatigue stress range,  $F_{Sr}$ , computed from the AASHTO Specification, Table 10.3.1A, Category F.

The attachment of these details shall not be allowed where the stress exceeds  $F_{Sr}$ .

- (e) The contract plans and shop drawings shall clearly show the flange areas where no welding is permitted and the areas on continuous girders where the stiffeners are to be connected to the top or bottom flanges. See Guide Sheet Plate 3.9 -21 for weld terminations.

#### **1.24.15 SHEAR LOCKS**

- (a) Shear locks shall be provided when a longitudinal expansion joint is located in the roadway area per Subsection 1.20.4 b. of this Manual. The shear locks shall be located at intermediate diaphragms within the middle half of the span. A minimum of three shear locks shall be provided per span. The shear locks are intended to eliminate differential deflections due to live load and impact.
- (b) Typical details to be used as a guide for preparation of contract drawings are illustrated on Guide Sheet Plate 3.9-9.

#### **1.24.16 FLARED DECKS**

Beams should be laid out parallel as much as practicable. Non-parallel beams shall be kept to a minimum.

#### **1.24.17 FIELD SPLICES**

- (a) To facilitate the fabrication, shipping and the erection of steel girders, one optional field splice will be permitted in spans between 35 and 45 meters in length. This field splice shall be located between the  $\frac{1}{3}$  and outer  $\frac{1}{4}$  points of the span length.

When the span exceeds 45 meters, optional field splices may be located between each of the  $\frac{1}{3}$  and outer  $\frac{1}{4}$  points.

In continuous spans, the bolted field splice shall preferably be made at or near the points of dead load contraflexure.

- (b) Locations and details of the optional field splice shall be shown on the plans. The Contractor may request modifications subject to approval by the Engineer.
- (c) Field splices shall be designed and detailed using AASHTO M 164M/M 164 (ASTM A 325M/A 325) high strength bolts. The flanges should have sufficient excess area at points where splicing is anticipated to permit a bolted splice to be made.
- (d) Splice locations are generally selected near transitions in flange thickness or width where there is sufficient flange area to permit hole drilling while still maintaining the required net area.
- (e) When rolled beams are used for continuous structures, the field splices should be located in areas where no cover plates are required. Consideration should be given to the fact that the fatigue strength of the section adjacent to the bolted connection (Category B\*) is less than the fatigue strength of the base metal in areas where there is no splice (Category A\*).

\*See Article 10.3 of the AASHTO Standard Specifications for Highway Bridges.

- (f) See Subsection 1.20.5 g. of this Manual concerning depth of concrete haunch at location of field splices.

#### **1.24.18 CLEANING AND PAINTING SYSTEMS**

- (a) Completed studies have determined the exposure effects of air pollutants and sea salt on structural paint. Accordingly, the State of New Jersey had been broken down into four environmental zones which are listed on Page 1.24-16. The current structural steel paint systems used by the Department are acceptable for use in all four environmental zones.
- (b) Though pollutant levels are relatively high in certain sections of the state as compared to ambient air quality standards, there is no evidence to show that repainting schedules are adversely affected. Thus industrial and rural areas should normally be considered comparable with regard to the use of structural steel paint systems. Unusual situations such as structures over or near factories might require individual study.
- (c) The effect of salt splash water on the deterioration of structural paint is dependent upon its salinity. Waters with salinity high enough to require

appropriate paint specifications include all coastal waters (Bays, Harbors, etc.) and coastal parts of tidal rivers. Splash zones of tidal rivers in New Jersey are specified by the following table:

<b><u>RIVER:</u></b>	<b><u>Splash Zone</u></b>
Delaware	Bridgeport, NJ
Mullica	23rd kilometer of River's Length
Hudson	New York Border
All other tidal rivers	24th kilometer of River

Note: Salt splash zones are areas 4.6 meters or less above the high water level.

- (d) Certain areas of the State through their configuration with the ocean are subjected to high concentrations of sea salt suspended in the air. Such salt intrusion would generally be limited to a 3 kilometer coastal region (see Pages 1.24-15 and 16).

The following notes are included to clarify the map on the previous page:

1. A river's point of measurement is to start where the mouth noticeably changes into a bay or ocean.

Examples: Hackensack and Passaic Rivers ..... Newark Bay  
Mullica River ..... Great Bay  
Raritan River ..... Line parallel from South Amboy to  
opposite coastline  
Shrewsbury River ..... Sea Bright Bridge

2. Sea salt intrusion areas are surrounded on three sides by salt water (peninsula, protrusion) such that at least one side faces open ocean or, are those land masses completely surrounded by salt water.
3. Except for the Delaware and Hudson Rivers, designated splash zones are only approximations of splash zones on rivers.
4. Dashed lines denote transition points from splash zones to 3 kilometer intrusion zones.

(e) Listed below are the four environmental zones identified in the State of New Jersey:

- ZONE 1 - Rural or industrial, mild exposure. Where severe corrosion is not a problem.
- ZONE 2 - Industrial, sever exposure. Area where corrosion is a serious problem. Progressively aggressive industrial locations.
- ZONE 3A - Marine, mild exposure. Structural steel more than 4.6 meters above mean high water. Structure located in less severe coastal salt intrusion zone.
- ZONE 3B - Marine, severe exposure. Structural steel less than 4.6 meters above mean high water. Structure located in severe coastal salt intrusion zone.

The cleaning and painting systems for structural steel shall be selected on a project to project basis and shall be established based on the guidelines listed in the table on the next page. For all projects involving painting of existing structural steel, a written request shall be submitted to the NJDOT Bureau of Maintenance Engineering for determination of the coating system to be specified.

Also, a request should be submitted to the Bureau of Project Support to request an EPA ID number. The EPA ID manifest number shall be listed on the manifest for processing of the waste. A minimum of two (2) weeks is required to obtain this information.

The Bureau of Maintenance Engineering and the Bureau of Project Support should be given the structure number, location ( highway route number or road name and milepost), municipality, zip code and County.

Coating System	Paint System	Surface Preparation	Acceptable Environmental Zones	Selection Criteria
IEU	P: Inorganic Zinc Rich I: Epoxy Polyamide F: Aliphatic Urethane	Near-White Blast Cleaning, SSPC-SP-10	All	Use for the painting of all new structural steel.
OEU	P: Organic Zinc Rich I: Epoxy Polyamide F: Aliphatic Urethane	Near-White Blast Cleaning, SSPC-SP-10	All	Use for all existing structural steel with an ASTM D610 Rust Grade of 6 or less and when no major structural work involving steel replacement is scheduled in the near future.
EU	P: Aluminum Epoxy Mastic I: Aluminum Epoxy Mastic F: Aliphatic Urethane	Hand/Power Tool Cleaning, SSPC-SP-2/3 (with spot commercial blast SSPC-SP-6 if and where directed)	All	Use for the painting of all existing structural steel with an ASTM D610 Rust Grade greater than 6.
Leave Steel Unpainted				Use this option for all existing structural steel with an ASTM D610 Rust Grade of 6 or less and when major structural work, involving steel replacement, is scheduled in the near future. (Use of this option will depend on site conditions)
Key: P=Primer      I=Intermediate      F=Finish				

- (f) The Standard Specifications provide color chip numbers for the following finish coat colors:

Foliage Green; Lake Blue; Brown

Brown should be specified only at those locations where a significant aesthetic objective is to be achieved. Brown should not be specified for Non-Redundant (Single-Load-Path) type bridges.

Other finish coat colors; such as, gray or off-gray may be used. The color chip number for these colors may be obtained by contacting the Bureau of Maintenance Engineering. The obtained color chip number should be provided in the Project Special Provisions.

- (g) The following notes are required on Structural Steel plans to compliment requirements of the Standard Specifications.

**Coating System:** \_\_\_\_\_

**Finish Coat Color:** \_\_\_\_\_

#### **1.24.19 BEARINGS**

The following guidance is to be considered for the design of new structures or for those projects that involve, as applicable, a superstructure replacement. For the seismic retrofit of existing bridges, Section 45 of this Manual should be referred to for guidance.

## **A. High Load Multi-Rotational Bearings**

Standard Drawings 2.5-1 and 2.5-2 may be referred to for a basic presentation of High Load Multi-Rotational Bearings. Section 14 of the AASHTO Standard Specifications for Highway Bridges, in addition to the following guidance, should be followed for guidance in designing such bearings.

### **1. General**

High load multi-rotational bearings, when used as fixed bearings, shall consist of a rotational element of the pot type, disc type or spherical type. When used as expansion bearings, sliding surfaces, to accommodate translation, shall be provided. Guide bars to limit movement in specified directions may also be provided.

Bearings shall be supplied as fixed bearings, guided expansion bearings or non-guided expansion bearings. Bearings shall adequately provide, as applicable, for the thermal expansion and contraction, rotation, camber changes and creep and shrinkage of structural members. The materials, fabrication and installation shall be in accordance with the AASHTO Standard Specifications for Highway Bridges and the NJDOT Standard Specifications for Road and Bridge Construction.

- a. Fixed Bearings - Fixed Bearings shall allow rotation but no transverse movement in the bearing plane. Section 14 of the AASHTO Standard Specifications for Highway Bridges shall be referred to for applicable specifications concerning pot and disc fixed bearings.
- b. Guided Expansion Bearings - Guided expansion bearings shall allow rotation and longitudinal movement in the bearing plane. Transverse movement shall be restricted. Section 14 of the AASHTO Standard Specifications for Highway Bridges shall be referred to for applicable specifications concerning guided pot and disc expansion bearings.
- c. Non - Guided Expansion Bearings - Non - guided expansion bearings shall allow rotation, longitudinal movement and transverse movement in the bearing plane. Section 14 of the AASHTO Standard Specifications for Highway Bridges shall be referred to for applicable specifications concerning non - guided expansion pot and disc bearings.
- d. The use of multi - rotational bearings shall be considered where the following conditions exist:
  - Low profile, high load bearings are required.
  - Curved or skewed bridges and other similar structures of complex design are required.

- Long slender columns or light frames and members exhibit minimum stiffness or rigidity.
- The direction of rotation varies.
- The direction of rotation can not be precisely be determined.
- Self aligning capabilities are required.
- Load and rotation eccentricity does not significantly alter the net distribution of stress through the bearing and into the substructure and superstructure.
- It is desirable to reduce the moment applied to truss or space frame panels.
- Large movements are required.
- Economical, long life, zero or low maintenance are desirable.

## 2. General Design Considerations

- a. Only one fixed or guided expansion bearing shall be assumed to resist the sum of all the horizontal forces at each abutment, bent, column, hinge or pier. Seismic forces are an exception as these forces may be resisted by all fixed or guided expansion bearings located at a given substructure unit. Longitudinal loads are resisted only at fixed bearings, and transverse loads resisted by fixed and guided expansion bearings.
- b. Provide at least two fixed or guided expansion bearings, each able to resist all horizontal forces at each abutment, column, hinge or pier for design redundancy.
- c. Multi-rotational bearings conforming to these guidelines shall not be used at vertical loads that are less than 20 percent of their capacity. Bearings for less than 20 percent require a special design. Special designs are also required where high horizontal and/or vertical loads are anticipated.
- d. Frictional resistance of bearing slide surfaces shall be excluded when specifying horizontal load requirements.
- e. Alignment of bearing guiding systems relative to the anticipated movement direction of the structure shall be carefully considered so as to avoid failure of the bearing guide system. Special studies or designs may be required on curved or skewed structures to ensure correct alignment.
- f. The substructure and superstructure shall be designed so that the sole and masonry plates remain rigid under all service conditions in areas around and in contact with the bearings.
- g. The substructure and superstructure design shall permit bearings to be removed for inspection or rehabilitation with minimal jacking of the structure.

- h. Avoid specifying total clearance of more than 1.6 mm between guides and guided components where possible.
- i. The clearance between bearing guides or keys and guided members shall be 1.6 mm.
- j. The minimum design rotation of bearings covered in these guidelines shall be 0.03 radians. This includes a construction tolerance of 0.02 radians.
- k. Friction coefficients shall be in accordance with Section 14 of the AASHTO Standard Specifications for Highway Bridges.

### 3. Construction Document Requirements

Contract documents shall include a “bearing schedule” that indicates the following information:

- a. A schedule of all minimum and maximum vertical and horizontal service loads without group factors for AASHTO Load Groups as shown in the Table on the following page. This will include all longitudinal forces and transverse forces as well as seismic forces.
- b. Minimum design rotation requirements of the bearing and construction tolerance.
- c. Magnitude and direction of movements at all bearing support points including thermal, creep and shrinkage movements.
- d. The location, quantity and type of each bearing (fixed, expansion or guided expansion) and the location of all bearing units. An actual bearing layout is preferred or a bearing framing plan to provide this data may be used.
- e. In Accordance with Subsection 8.15.2.1.3 of the AASHTO Standard Specification for Highway Bridges, the allowable stresses and allowable upper and lower bearing contact pressure to be used in the bearing design.
- f. All anchorage details and requirements.
- g. Details to provide all grades, bevels and slopes at each bearing location.
- h. The coefficient of friction that is used in designing the sliding surfaces.
- i. Special details that may be needed for earthquake requirements; such as, uplift details or temporary attachments.
- j. Surface coating requirements to include coating specifications and

specific surfaces to be coated.

- k. Field welding of the sole plate to the beam shall be permitted by qualified welders.

#### FORMAT FOR LOAD PORTION OF BEARING SCHEDULE

Notes: The forces in the table shall be actual service loads.

This table should be provided for every bearing type. Engineering judgment should be used to eliminate groups which obviously will not control the bearing design in order to limit the table size.

GROUP	SERVICE LOADS						
	VERTICAL			HORIZONTAL			
	DL	LL + I		TRANSVERSE		LONGITUDINAL	
		MIN	MAX	MIN	MAX	MIN	MAX
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

#### 4. Design Requirements

- a. Multi-rotational bearings shall be designed to accommodate the loads, forces and movements specified in the bearing schedules.
- b. Maximum design stresses for all bearing components shall not exceed the allowable design stresses of the current AASHTO Standard Specification for Highway Bridges.
- c. The minimum design rotation capacity shall be 0.03 radians or

greater. This will include a construction tolerance of 0.02 radians.

- d. The minimum horizontal load capacity for fixed or expansion bearings shall be 10 percent of the vertical load capacity.
- e. Bearings shall be designed for the total movement capacity plus 25.4 mm additional movement in each direction. The spacing between the bearing guides does not require the additional movement capacity. The centerline of all bearing components will be symmetrical about the bearing stiffener. The value used for the full anticipated movement shall be made equal to twice the amount of contraction.
- f. The sole plate above the bearings shall be tapered as needed so that the distance between the top of the pot and the sliding surface does not deviate from the general uniformity by more than 3.2 mm under all dead loads.
- g. The stainless steel plate mounted on the sole plates to permit full expansion and contraction for pot or disc bearings should be extended to within 6.4 mm of the edge of the sole plate.
- h. Complete design calculations shall be provided prior to submission of shop drawings on all projects for all aspects of pot, disc and spherical bearings.
- i. Designers shall be responsible for the design of all aspects of the pot bearing except the pot wall thickness, the height and the pot base thickness.
- j. Pot Bearings

The following items must be designed:

- 1.) pot diameter
- 2.) piston shaft diameter (Min.), piston bottom diameter (Min.), and sealing rings
- 3.) elastomeric disc
- 4.) masonry plate size and thickness
- 5.) sole plate size and thickness
- 6.) guide plate thickness, length, and width (Min.); piston to guide plate weld size (Min.)
- 7.) sliding surface dimensions; length of teflon strip and width (Min.); number of flat head socket screws per teflon strip

- 8.) all connection requirements including weld sizes and size of bolts, cap screens, and anchor bolts

k. Limitations of Pot Bearings

Pot bearings are not stiff against bending in their plane. A sole plate, beveled if necessary, on top and a masonry plate at the bottom of the bearing shall be provided. Pot bearings have a limited capacity of rotation; they shall not be mixed with other types of bearings.

5. DESIGN OF ROTATIONAL ELEMENTS - POT BEARINGS

a. Pot

- 1.) Pot inside diameter shall be the same as the elastomeric disc. Depth of pot cavity in millimeters shall be equal to or greater than

$$[(\text{PotID}/2) \times (\text{Design Rotation (radian)})] + 0.1 + k + \text{thickness of Elastomeric Disc} + \text{Piston Face Width}$$

where:

- Design rotation includes live load rotation and all other pertinent rotations including construction tolerance.
- $k = 1.7 \times$  the ring cross-section diameter for round brass rings where rings sit 100 percent in the piston chamfer.
- $k = 1.2 \times$  the ring cross-section diameter for round brass rings where rings sit 50 percent recessed in the elastomeric disc and half in the piston chamfer.
- Piston face width is the part of the edge of the piston which contacts the pot wall.

- 2.) The section thickness of the pot beneath the elastomer shall be no less than:

- Pot ID  $\times 0.06$  for bearings directly on concrete but not less than 19.0 millimeters.
- Pot ID  $\times 0.045$  for bearings directly on steel masonry plates but not less than 12.7 millimeters.

- 3.) Minimum outer plan dimensions of pots shall be determined by analyzing horizontal loads, internal elastomer pressure, and piston force due to friction, shear, bending, and tension, but the wall thickness shall not be less than 19.0 millimeters.

- 4.) Pots shall be connected to the masonry plate by either setting the pot in a recess designed for horizontal loads or by welding the pot to the masonry plate. If the pot is set in a recess, proper drainage is required.

b. Elastomeric Disc

Elastomeric discs shall be designed and detailed to meet the following minimum requirements:

- The minimum thickness of elastomeric discs shall be defined as  $\text{thickness in millimeter} = \text{Design Rotation (Radian)} \times (\text{Disc Diameter (millimeters)} / 0.3)$ .
- Area of elastomeric disc shall be designed for a maximum average stress of 24 MPa +/- 5 percent at the total dead and live loads of the structure.
- The disc shall be lubricated with a material compatible with the elastomer.

c. Piston

Design and detail the piston to meet the following minimum requirements:

- 1.) Outside diameter shall be 6.4 millimeters less than the nominal pot Inside Diameter (ID).
- 2.) Piston thickness shall be sufficient to provide clearance between the top of the pot and the sliding surface as follows:
  - a) For square pots,  $\text{Clearance} = (\text{Design Rotation (radian)}) \times (0.7 \times \text{Pot side (millimeters)})$ .
  - b) For round pots,  $\text{Clearance} = (\text{Design Rotation (radian)}) \times (\text{Pot OD (millimeters)} / 2) + 3.0$ .
- 3.) Where the seal is wholly within the piston thickness, pistons for round seals shall have the lower corner chamfered at 45 degrees for a depth equal to 1.7 times the diameter of the seal and 1.2 times the diameter where the seal extends into the elastomer.
- 4.) When designing for horizontal forces, the piston face width shall be designed assuming contact area with pot wall as one third the circumference with an allowable stress of 0.8 Fy.

d. Elastomer Sealing Rings

Design and detail the elastomer sealing rings to meet the following minimum requirements:

- 1) Flat sealing rings are not permitted.
- 2) Round Sealing Rings
- 3) Round sealing rings shall have the following minimum diameters:
  - Up to 556 kN - 4 mm
  - Up to 1780 kN - 5 mm
  - Up to 3558 kN - 8 mm
  - Up to 6227 kN - 10 mm
  - Up to 22240 kN - 13 mm
- 4) Rings shall be rolled into a circle from rod and brazed or welded, and they shall fit the pot snugly so that they are in contact with the pot wall when installed.

## 6. DESIGN OF ROTATIONAL ELEMENTS - DISC BEARINGS

### a. Disc

- 1.) Elastomer discs shall have a minimum thickness equal to:
  - a.)  $[(\text{deflection due to compression load}) + 0.5 \times (\text{disc diameter}) \times (\text{design rotation})] \times [e_c = \text{strain due to all effects but } < 15\%]$ .
  - b.) Area of disc shall be designed for a maximum working stress of 25 MPa +/- 5 percent for Polyether Urethane Compound A and 34 MPa +/- 5 percent for Polyether Urethane Compound B at the total dead and live loads of the structure.

### b. Bearing Plates

- 1.) A limiting ring shall be provided by a welded ring or by matching a recess in the bearing plate. The depth of the limiting ring shall be equal to or greater than  $ID \times 0.014$ . The inside diameter of the retainer ring shall be greater than the diameter of the disc by 4 to 6 percent of the diameter.
- 2.) The section thickness of the plate beneath the disc, where not

limited by bending stresses shall not be less than:

- a.) Disc OD X 0.06 for bearing directly on concrete but not less than 19.0 millimeters
  - b.) Disc OD X 0.045 for bearing directly on steel masonry plates but not less than 12.7 millimeters
- 3.) Connect bearing plates to masonry plates by means of a fillet weld around the entire perimeter. Full clearance shall be maintained between the bearing parts for the following conditions:

Design Rotation (radians) + Vertical Deflection

- 4.) The shear restriction mechanism shall be designed to allow free rotation and withstand the specified horizontal forces. The mechanism shall be designed to withstand shear, bending, and bearing stresses and shall be connected to the bearing plates by welding or other acceptable means.

7. DESIGN OF ROTATIONAL ELEMENTS - SPHERICAL WITH PTFE/STAINLESS STEEL SURFACES

a. Spherical Element - Concave Surface - Polytetrafluoroethylene (PTFE)

- 1.) The spherical radius shall be determined such that the resulting geometry of the bearing is capable of withstanding the greatest ratio of horizontal load to vertical load under all loading conditions to prevent unseating the concave element.
  - 2.) If required during construction, mechanical safety restraints shall be incorporated to prevent overturning.
  - 3.) Maximum design rotation of the structure itself plus 0.02 radians shall be considered in the bearing design to prevent overturning or uplift.
  - 4.) Calculations showing the determination of the radius shall be submitted for approval.
  - 5.) The projected area of sheet PTFE shall be designed for maximum working stress in accordance with Section 14 of the AASHTO Standard Specification for Highway Bridges, Division 1.
  - 6.) The projected area of woven fiber PTFE shall be designed for a maximum working stress in accordance with Section 14 of the AASHTO Standard Specification for Highway Bridges, Division 1.
- a.) The concave surface shall face down.

- b.) The minimum edge and center thickness shall be 19 millimeters.
  - c.) For sheet PTFE the minimum thickness shall be 3.2 millimeters and recessed for 1.6 millimeters in the spherical element.
  - d.) PTFE fabric shall be a minimum of 1.6 millimeters and a maximum of 2.4 millimeters thick when measured in accordance with ASTM D1777.
- b. Rotational Elements - Concave - Spherical - Bronze
  - 1) The spherical radius shall be determined such that the resulting geometry of the bearing is capable of withstanding the greatest ratio of horizontal force to vertical load under all loading conditions to prevent unseating the concave element.
  - 2) If required, mechanical safety restraints shall be considered to prevent overturning.
  - 3) The maximum design rotation of the structure which includes a 0.02 radian construction tolerance shall be considered in the bearing design to prevent overturning or uplift.
  - 4) Calculations showing the determination of the radius shall be submitted for approval.
  - 5) The spherical element shall be made from the following or other approved bronze alloys:
    - Type 1 - ASTM B22 Alloy C90500
    - Type 2 - ASTM B22 Alloy C91100
    - Type 3 - ASTM B22 Alloy C86300
  - 6) The maximum design compressive stress for the projected area shall be:
    - Type 1 - 14 MPa
    - Type 2 - 17 MPa
    - Type 3 - 21 MPa
  - 7) The bearing surfaces shall have lubricant recesses consisting of concentric rings with or without central circular recesses with a depth at least equal to the width of the rings or recesses.
  - 8) The recesses or rings shall be arranged in a geometric pattern so that adjacent rows overlay in the direction of motion.
  - 9) The entire area of all bearing surfaces that have provisions for relative motion shall be lubricated by means of the lubricant-filled recesses.

- 10) The lubricant-filled areas shall comprise not less than 25 percent of the total bearing surface.
- 11) The lubricant compound shall be integrally molded at high pressure and compressed into the rings or recesses and project no less than 0.25 mm above the surrounding bronze plate.

c. Rotational Elements - Spherical Concave Surfaces

- 1.) The convex element shall be designed for the following service rotation in radians:

$$\text{Service rotation} = \text{"Design Rotation"} + 0.03$$

where design rotation refers to the rotation (radians) of the structure itself.

- 2.) Minimum edge and center thicknesses shall be no less than:
  - a) OD X 0.06 for bearings directly on concrete
  - b) OD X 0.045 for bearings on steel masonry plates
  - c) 12.7 millimeters
- 3.) If sheet PTFE is used for guided surfaces, it shall be pigmented.

d. PTFE sliding surfaces shall meet the following requirements:

- 1.) PTFE sliding surfaces shall be designed for working stress at the dead and live load of the structure, in accordance with AASHTO Division 1, Section 14.
- 2.) Sheet PTFE shall be a minimum of 3.2 millimeters thick, epoxy-bonded into a square-edge recess 1.6 mm deep.
- 3.) Fabric PTFE shall have a minimum thickness of 1.6 millimeters and be epoxy-bonded to the substrate using a system that prevents migration of epoxy through the fabric. Any edges other than the selvedge shall be oversown or recessed so that no cut fabric edges are exposed.

e. Stainless Steel Sliding Surfaces

Stainless steel surfaces shall meet the following requirements:

- 1.) The stainless steel surface shall cover the mating surface in all operating positions plus 25 mm in each direction of movement or extend to the end of sole plate whichever is greater.

- 2.) Sheet stainless steel shall be 1.5 millimeters to 2.1 millimeters gauge thick and connected to the substrate by a continuous weld around the entire perimeter. The sheet shall be in full contact with the substrate.
- 3.) Stainless steel sliding surfaces shall face down.
- 4.) Stainless steel welded overlay shall be a minimum of 1.5 millimeters to 2.1 millimeters thick after welding, grinding, and polishing, and produced using Type 309L electrodes.

## 8. GUIDE BARS

- a. Guide bars may be integral by machining from the solid or by welding or connecting with high-strength fasteners. High-strength fasteners shall be designed using  $0.25 \times$  Ultimate Shear Strength.
- b. Guide bars shall be designed for the specified horizontal forces, but not less than 10 percent of the vertical capacity of the bearing. The total space between the guide bars and guided members (both sides) shall be 1.6 millimeters maximum. Guided members shall give their contact area within the guide bars in all operating positions. Guiding off the fixed base or any extensions of it is not permitted.
- c. PTFE must be used on guides and shall be bonded to and recessed in their substrate. The screws shall be recessed a minimum of 50% of the amount of protrusion of the PTFE above the guiding surface.
- d. PTFE used on guide bars shall be pigmented.

## B. Elastomeric Bearings

Section 14 of the AASHTO Standard Specifications for Highway Bridges shall be referred to for guidance in the design of elastomeric bearings. The following information is offered in determining the suitability of elastomeric bearing application.

1. Elastomeric bearings have been developed to provide a maintenance free device capable of accommodating expansion and rotation by utilizing the unique characteristics of the elastomeric material.
2. Elastomeric bearings are generally placed between sole plates and masonry plates. In some instances, they can be placed directly between the superstructure member and the substructure unit.
3. Elastomeric bearings are available in three basic types as follows:
  - Plain elastomeric pads
  - Steel reinforced elastomeric pads
  - Fabric reinforced pads (usually a fiberglass composition)

4. Laminations can be created in the elastomer by introducing a layer of steel or fabric between the layers of elastomer. The sheets separating the layers of elastomer are completely encased within the elastomeric material. For vertical loads, each layer of the elastomer behaves like an individual pad, while the horizontal strain is additive to each layer. That is, as layers are applied, the allowable horizontal strain is increased. Therefore, adding laminations is a convenient way to accommodate larger lateral movements for the same compressive loads.

5. As required by the AASHTO Standard Specifications for Highway Bridges, elastomeric materials shall have a hardness of from 50 to 70 durometers.

6. Superstructures composed of prestressed concrete box beams or I-beams with spans of 38 meters or less may be considered for use of plain or laminated elastomeric pads. A potential horizontal movement of 50.8 to 76.2 millimeters should be considered when analyzing such use.

7. When permitted by design conditions, elastomeric pads may not be bonded to the superstructure and substructure concrete surfaces. In such cases, restraining lips or keeper plates should be provided around the pads. This will inhibit the potential of the pads walking off the bearing locations.

8. Elastomeric bearings may be provided with PTFE sliding surfaces. The elastomeric material is used to accommodate rotation and a PTFE surface mated with a stainless steel plate will handle lateral movement.

In such applications, keeper plates should be provided to restrain the movements. Provision of restraining bars to limit the movement of the elastomeric material and to enable the PTFE sliding surface to accommodate the movement should also be considered.

### **C. Seismic Isolation Bearings**

1. The basic intent of seismic isolation is to increase the fundamental period of vibration such that the structure is subject to significantly lower earthquake forces. The reduction in forces is accompanied by an increase in displacement demand which must be accommodated with a flexible mount.

The following elements describe the basic composition of a bridge seismic isolation system:

- A flexible mounting so that the period of vibration of the bridge is lengthened sufficiently to reduce the force response.
- A damper or energy dissipator so that the relative deflections across the flexible mounting can be limited to a practical design level.
- A means of providing rigidity under low (service) load levels such as wind and braking forces.

2. Rather than resisting the large forces that are generated by earthquakes, seismic isolation systems decouple the bridge deck from the ground motion. When used in combination with a flexible device such as an elastomeric bearing, an energy dissipator can control the response of an isolated structure by limiting both the displacements and the forces.

3. Seismic Isolation bearings shall be designed in accordance with Section 14 of Division I and constructed in accordance with Section 18 of Division II of the AASHTO Standard Specifications for Highway Bridges.

Standard Drawing number 2.5-3 may be referred to for a basic presentation of Seismic Isolation Bearings. This drawing is for informational purposes only and is not to be included in a contract set of plans.

4. Seismic design, performance and testing shall be assessed in accordance with the AASHTO Guide Specifications for Seismic Isolation Design.
5. Seismic Isolation bearing assemblies shall include seismic isolation bearings (isolators), sole plates, masonry plates, mounting plates, lead cores, steel shims, bolts, washers and anchor bolts.

The isolators shall consist of one of the following types:

- Elastomeric bearing with lead core type consisting of alternate layers of natural rubber and steel plates with a preformed hole at the center of the unit that is filled tight with a pure lead plug. The elastomeric bearing shall be vulcanized to the top and bottom load plates.
- Sliding bearing type consisting of PTFE stainless steel surfaces that are used in conjunction with an optional spring/damping assembly.

6. The following loads will govern the design of the various components of the bearing assembly:

- Vertical Loads will govern the plan size of the assembly and the internal rubber layer thickness.
- Short term loads will govern the lead core diameter.
- Long term displacements will govern the total rubber height and the lead core diameter.
- Imposed rotations will govern the internal rubber layer thickness and the total rubber height.

7. The Designer shall identify if the use of a seismic isolation bearing system is suitable for the retrofit or new design of a bridge structure.

- a. If deemed suitable, and as per the requirements of Section 503 of the NJDOT Standard Specifications, the Designer shall provide sufficient

information to facilitate the selection and design of the bearing assembly by the Contractor.

- b. Section 503 of the NJDOT Standard Specifications provides a list of qualified isolation bearing suppliers. These suppliers should be consulted to verify appropriate requirements.
8. The Contract Plans shall provide conceptual dimensions of the isolators that have been identified for use in a project.
  - a. The beam seat elevations, as detailed in the plans, shall be based on the conceptual dimensions. Any required change in the height of the isolators shall be compensated by adjustments, first, to the concrete masonry and sole plates, and, second, if necessary, to the beam seat elevations.
  - b. Changes to the plan dimensions shall take into consideration the physical limits of the beam seats. As detailed on the plans, all isolators shall be centered directly beneath the girder webs.
9. The following Tables may be used as a guide in providing necessary provisions to facilitate the bearing assembly design. Comparable tables should be provide in the contract plans. The indicated values are for example purposes only.

Designers shall perform these type calculations to identify that the isolation system complies with the relevant provisions of the AASHTO Standard Specifications for Highway Bridges.

Maximum Non-Seismic Loads per Isolator (See Note 1.)

Location	Dead Load (kN)	Live Load (kN)
End Bents 1, 2	578	289
Pier 1, 2	601	249

Maximum Non-Seismic Loads per Substructure (See Note 2)

LOCATION	Maximum Displacement (D) and Force (F) due to Temperature <sup>3</sup>		Maximum of Factored AASHTO Load Groups II - VI <sup>3</sup>		Unfactored Wind Load (W) and Corresponding Displacement (D)	
	D (mm)	F (kN)	Longitudinal (kN)	Transverse (kN)	W (kN)	D (mm)
End Bents 1, 2	30.5	423	636	494	378	7.6
Pier 1, 2	7.6	111	130	13	9	7.6

Note 1: Factors of safety shall satisfy Sections 14(Division I) and 18 (Division II) of the AASHTO Standard Specifications for Highway Bridges.

Note 2: These are the maximum of the factored loads for AASHTO load groups II through VI that are to be used for isolator design. Other conditions may control substructure design.

Note 3: There shall be no increase or decrease in the overall height of any isolator due to thermal displacements that results in a change of more than 3 mm in the pavement profile.

#### **D. Bearing Selection Evaluation**

1. The bearing type selection should be based on achieving the most economical solution that will support all required movements. An initial evaluation will reveal that elastomeric bearings or elastomeric bearing pads will often be the lowest maintenance and most economic solution as a bearing selection.
2. Economics should not be the sole category in selecting bearing types. Accommodating longitudinal, transverse and rotational movements as well as consideration of governing skew controls should be evaluated in the bearing selection.